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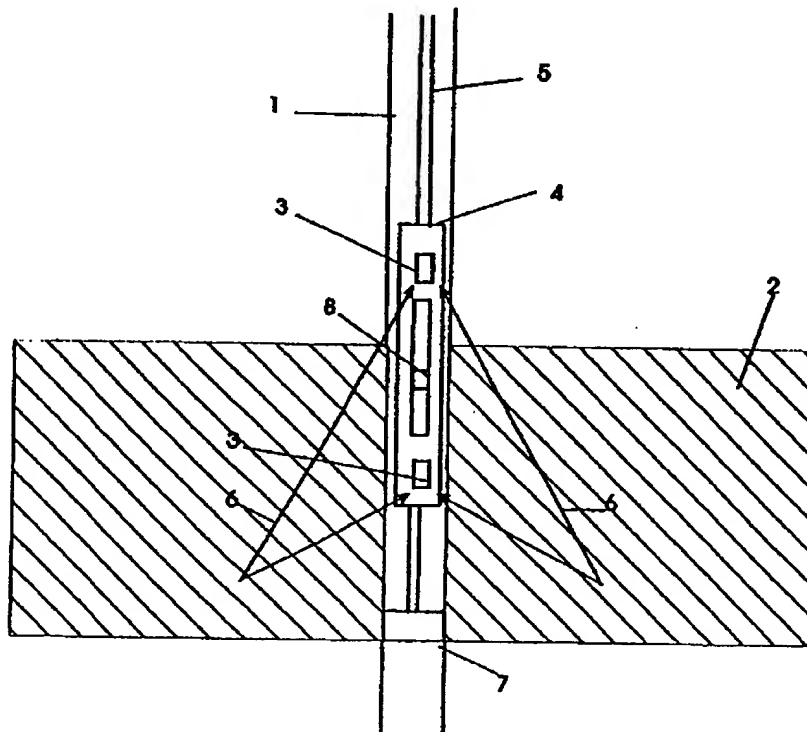
## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(54) Title: ENHANCED DETECTION METHOD

## (57) Abstract

A method and apparatus for determining properties of rocks surrounding a borehole in which electrokinetic signals are generated in the rocks e.g. by the vibration induced by the drilling of the bore hole or by a seismic source emitting continuous pressure waves and the electrokinetic signals generated are detected by a detection means down the borehole and the signals amplified and processed to measure the porous rock properties.



### Enhanced Detection Method

The present invention relates to a method and equipment for measuring the properties of subsurface rock from a module close to the drilling bit operating during drilling. In particular it relates to a method and equipment for measuring such properties as the response time and amplitude of the electrokinetic response and deducing the pore fluid electrical conductivity, porosity and permeability of fluid-bearing porous rocks.

The measurement of permeability of rocks surrounding a borehole is important in assessing the location of water or oil reserves, including the quality and quantity of the reservoir rock. Existing methods are unable to measure the permeability of a porous rock directly with any accuracy from a downhole tool. It is valuable to measure the properties of a formation during drilling usually called logging while drilling (LWD) in order to vary the drilling as a response (called geosteering).

In addition to its value in the assessment of the quality and distribution of porous rock containing water or oil in reservoirs, the rock permeability is very important in determining at what rate and at what cost these fluids can be produced from production wells.

US Patent 3,599,085 describes a method in which a sonic source is lowered down a borehole and used to emit low frequency sound waves. Electrokinetic effects in the surrounding fluid-bearing rock cause an oscillating electric field in this and is measured at at least two locations close to the source by contact pads touching the borehole wall. The electromagnetic skin depth is calculated from the ratio of electrical potentials and the permeability of the rock deduced. US Patent 4,427,944 and the equivalent European Patent 0043768 describe a method which injects fluid at high pressure from a downhole tool to generate electrokinetic potentials; these are measured by contact electrodes against the borehole wall. The risetime of the electrical response is measured and from this the permeability of the porous rock is determined.

UK Patent 2,226,886A and the equivalent US Patent 4,904,942 describe several arrangements for recording electrokinetic signals from subsurface rocks mainly with the electrodes for measuring the signals at or close to the earth's surface but including

use of an acoustic source mounted on a downhole tool. There is no indication of permeability being deduced or of inferring porosity. A further related (inverse) method is described in European Patent 0512756A1, which contains several arrangements for setting out electrical sources and acoustic receivers (geophones) in order to measure electro-osmotic signals induced in subsurface rocks.

PCT Patent WO 94/28441 describes a method whereby sound waves of fixed frequency are emitted from a downhole source and the resulting electrokinetic potentials measured. An electrical source of fixed frequency is then used to produce electro-osmotic signals and the acoustic response measured. Using both responses together, the permeability is then deduced, provided the electrical conductivity of the rock is also separately measured.

In these methods the seismic shock is generated downhole at intervals and require a separate means for generating the signals downhole.

We have now devised an improved method for measuring the properties of porous rocks.

According to the invention there is provided a method for determining properties of rocks surrounding a borehole in which method electrokinetic signals generated in the rocks by the vibration induced by the drilling of the bore hole or by a seismic source emitting continuous pressure waves are detected by a detection means down the borehole and the signals processed to measure the porous rock properties.

Properties which can be measured by the method of the present invention include permeability, porosity and fluid properties such as viscosity, electrical conductivity and zeta potential.

The vibration signal produced by the drilling or by a seismic source is propagated outwards in all directions through the borehole fluid (the fluid in the borehole e.g. drilling mud etc.) and, subject to distortion by the borehole wall and variations in the rock, the signal propagates outwards substantially uniformly in all directions. The electrical signal generated within the surrounding rock is received and detected at the tool within the borehole from substantially all directions.

This invention also provides apparatus for measuring the properties of rocks surrounding a borehole, which apparatus comprises a module adapted to be lowered down a borehole in which module there is a means adapted to detect electrical signals generated in the rocks either by the seismic effect of the drilling of the borehole or by seismic signal emitted from the module.

The electrical signals can be detected by means of a pair of electrodes positioned within the borehole close to the borehole wall or, preferably, an electrode pair or short dipole antenna mounted downhole and positioned centrally and aligned axially within the borehole. In the equipment of the present invention it is convenient to use one or two electrical receivers spaced apart and preferably aligned vertically or horizontally at the centre of the borehole.

The electrical receiver preferably consists of one or two pairs of electrodes forming a short dipole antenna with electrically isolated ends. For each pair the electrodes are preferably connected to an amplifier which amplifies the signals whilst keeping them electrically isolated; this is carried out by referring the potential of each electrode independently to a floating reference potential. The signals are preferably amplified and converted to digital form before being communicated (e.g. by acoustic means) to the surface for recording and processing.

Preferably the means for detecting the electrical signals compares the potential at the ends of dipole antenna are compared by connecting them to an amplifier in which the potentials are preferably referred to a non-earthed reference (a virtual earth) and these new potentials are amplified and compared. Such a procedure allows amplification with very little distortion of the potential to be measured and with a high degree of common-mode noise rejection and is superior to other conventional methods of amplification.

Preferably the non-earthed reference potential is that of a common line in the amplification and data acquisition circuitry of the receiver and is not connected directly to earth.

The drilling of boreholes using conventional drilling means and drilling bits can generate vibrational and other shocks to the surrounding rocks in a range of

frequencies depending on the speed of the drill, nature of the rock, downward pressure etc.

The drilling can be carried out by any drilling means which generates suitable vibrations in the rocks, conventional drill bits drilling through rock generate vibrations in a wide range of frequencies and these vibrations surprisingly have been found to act to generate electrical effects in the surrounding rocks. The seismic waves generated by the drill bit can be measured by a transducer on the module which converts pressure variation to electrical signals so that they can be used for demodulation or recording.

Preferably the amplified electrical signals from the receiver are deconvolved with respect to the source frequencies and the amplitude and phase relative to the source sampled at a frequency of about 1-100 Hz per channel and converted from analogue to digital form. The digital data transmitted to surface is recorded as a data file and can then be processed.

Alternatively a source of seismic or acoustic signals can emit these from the module in order to achieve a more controlled source than the effect from drilling.

The amplitude and rate of response of electrokinetic signals to acoustic pulses have been shown to be closely related to the porosity and the permeability of the target porous rock. After processing of the amplitude of response at more than one frequency a log of rock permeability and porosity and also pore fluid conductivity can be produced which may also include fluid viscosity and rock zeta potential. Alternatively, if the amplitude and phase of the electrokinetic response at a single frequency are measured, the permeability and porosity may be derived from these.

It is believed that the method of the present invention makes use of an electrokinetic effect in which the seismic wave generated by the drilling on passing through the interface of the borehole with the surrounding porous rock and through interfaces within the rock where the fluid properties change, stimulates electrical signals detected at the receiving electrodes or coils. The oscillations within the porous rock give rise to fluid flow within the rock and as cations and anions adhere with differing strengths to capillary walls, a resulting electric dipole is generated within the rock. This electric dipole distorts the quasi-static electric field within the slightly conducting

medium of the rock and this distortion propagates back to the tool, where it is measured. The invention will now be described with reference to the accompanying drawings in which:-

Fig. 1 is a schematic view of the invention and

Fig. 2 is a circuit diagram showing amplifier connections

Referring to Figs 1 the downhole receiver module (4) is connected to the drill string (5) so that it can be raised and lowered down borehole (1). In the receiver module is an antenna comprising one pair of electrodes (3). In use, the vibrations and oscillations generated by the drilling using drilling bit (7) produce a seismic signal measured by a transducer (8) comprising continuous acoustic oscillations and this generates an electrokinetic signal (6) in the surrounding rock (2) which is detected by electrodes (3) and the amplitude and response time of this electrokinetic signal generated measured.

Referring to Fig. 2, the signal from the electrodes (4,5) pass to a pair of low-noise operational amplifiers (28) which provide keep the two channels isolated from each other. Preset balancing controls (29) control the balancing of common mode noise in each line before they are compared and amplified by a final stage amplifier (14). Signals from the transducer (8) pass through an amplifier (30) and are used at (31) to demultiplex the main signals, giving a response signal which is sent to surface (32).

## Claims

1. A method for determining properties of rocks surrounding a borehole in which method electrokinetic signals generated in the rocks by the vibration induced by the drilling of the bore hole or by a seismic source emitting continuous pressure waves are detected by a detection means down the borehole and the signals processed to measure the porous rock properties.
2. A method as claimed in claim 1 in which the vibration signal produced by the drilling or by a seismic source is propagated outwards in all directions through the borehole fluid and, subject to distortion by the borehole wall and variations in the rock, the signal propagates outwards substantially uniformly in all directions and the electrical signal generated within the surrounding rock is received and detected at the tool within the borehole from substantially all directions
3. A method as claimed in claim 1 or 2 in which the electrical signals are detected by means of a pair of electrodes positioned within the borehole close to the borehole wall.
4. A method as claimed in claim 2 in which the electrical signals are detected by an electrode pair or short dipole antenna mounted downhole and positioned centrally and aligned axially within the borehole.
5. A method as claimed in claim 4 in which the means for detecting the electrical signals compares the potential at the ends of the dipole antenna.
6. A method as claimed in claim 2, 3 or 4 in which, for each electrode pair, each electrode is connected separately to an amplifier which amplifies the signals whilst keeping them electrically isolated.
7. A method as claimed in claim 6 in which the potential at the ends of dipole antenna are compared by connecting them to an amplifier in which the potentials are referred to a non-earthed reference (a virtual earth) and these new potentials are amplified and compared.

8. A method as claimed in claim 7 in which the non-earthed reference potential is that of a common line in the amplification and data acquisition circuitry of the receiver and the amplifier earth is isolated from the data acquisition and other circuitry.
9. A method as claimed in claim 7 in which the non-earthed reference potential is that of a common line in the amplification and data acquisition circuitry of the receiver and is not connected directly to earth.
10. A method as claimed in claimed in any one of claims 3 to 9 in which there is provision for isolating and balancing the signals from each of the electrodes or coils before they reach the amplifier circuit in order to give the maximum common-mode rejection of electromagnetic noise.
11. A method as claimed in any one of claims 1 to 10 in which the signals are converted to digital form before being communicated to the surface for recording and processing.
12. A method as claimed in any one of preceding claims 1 to 11 in which the seismic waves generated by the drill bit are measured by a transducer on the module which converts pressure variation to electrical signals so that they can be used for deconvolution or recording.
13. A method as claimed in claim 12 in which amplified electrical signals from the receiver are deconvolved with respect to the source signal and the amplitude and phase relative to the source sampled at a frequency of about 1-100 Hz per channel and converted from analogue to digital form.
14. Apparatus for measuring the properties of rocks surrounding a borehole, which apparatus comprises a module adapted to be lowered down a bore hole in which module there is a means adapted to detect electrical signals generated in the rocks either by the seismic effect of the drilling of the borehole or by seismic signal emitted from the module.



15. Apparatus as claimed in claim 14 in which the means adapted to detect electrical signals comprise a pair of electrodes positioned within the borehole close to the borehole wall and their ends are connected to an amplifier which amplifies the signals whilst keeping them electrically isolated
16. Apparatus as claimed in claim 14 or 15 in which the means adapted to detect electrical signals comprise an electrode pair or short dipole antenna adapted to be mounted downhole and positioned centrally and aligned axially within the borehole.
17. Apparatus as claimed in claim 16 in which the potential at the ends of the dipole antenna are connected to an amplifier in which the potentials are referred to a non-earthed reference (a virtual earth) and these new potentials can be amplified and compared.
18. Apparatus as claimed in any one of preceding claims 14 to 17 in which there is a means for isolating and balancing the signals from each of the electrodes or coils before they reach the amplifier circuit in order to give the maximum common-mode rejection of electromagnetic noise.
19. Apparatus as claimed in any one of claims 14 to 20 in which there is a transducer on the module which converts pressure variation to electrical signals so that they can be used for deconvolution or recording.

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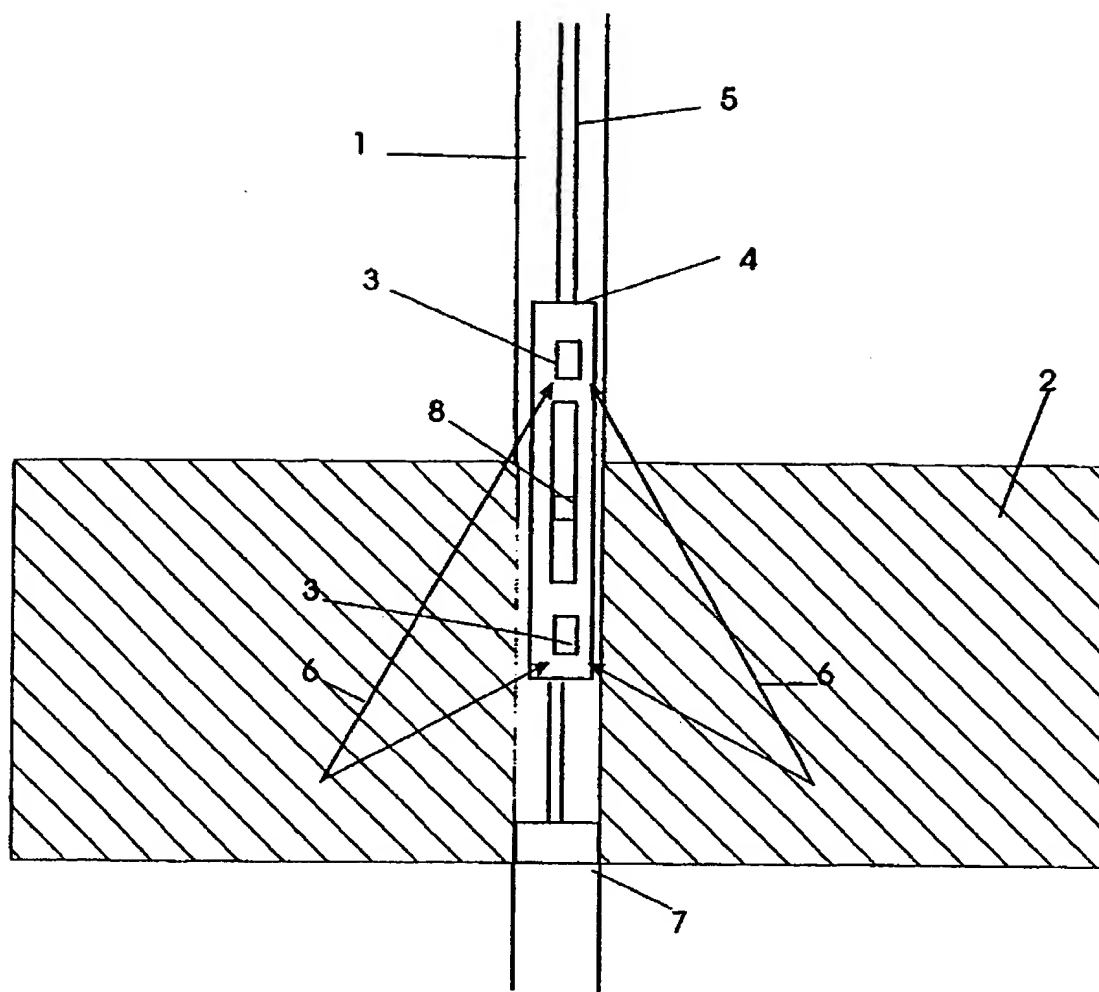


Fig. 1

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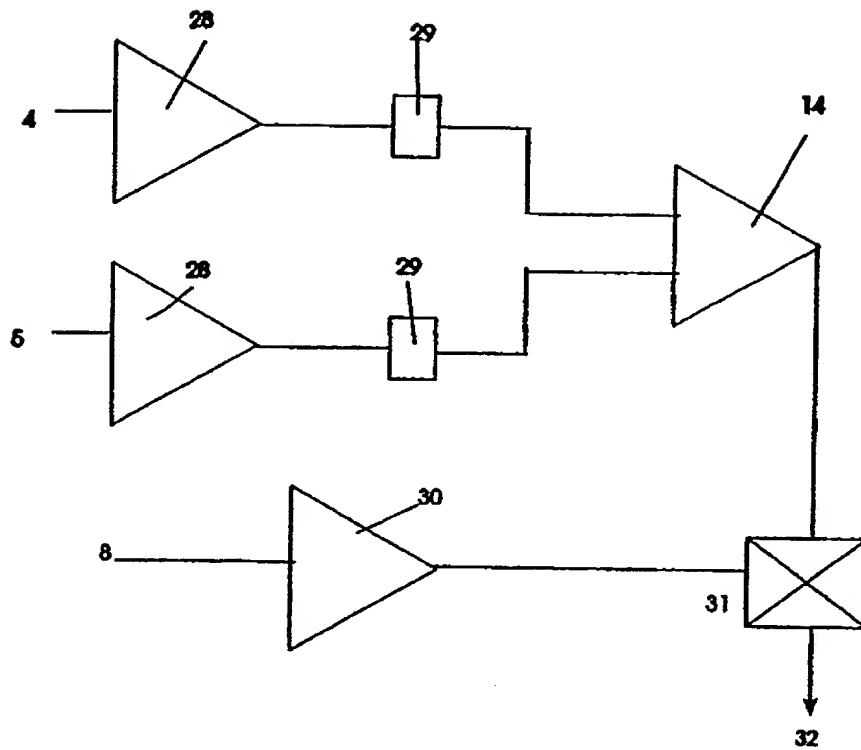


Fig. 2

## INTERNATIONAL SEARCH REPORT

International Application No.

PCT/GB 98/02234

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC 6 G01V3/26

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 GOIV

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97 14980 A (MILLAR JOHN WILLIAM AIDAN ;CLARKE RICHARD HEDLEY (GB)) 24 April 1997 see the whole document	1,3, 10-19 2,4-9
Y	WO 93 07514 A (ATLANTIC RICHFIELD CO) 15 April 1993 see abstract see page 20, line 1 - line 17 see page 26, line 24 - page 29, line 9 see figure 1	2,4-9
X	SU 1 772 775 A (NIZHEGORODSKIY NI RADIOFIZICHE) 30 October 1992 see abstract	1

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

\* Special categories of cited documents :

- A\*** document defining the general state of the art which is not considered to be of particular relevance
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- "Z" document member of the same patent family

Date of the actual completion of the international search

8 December 1998

Date of mailing of the international search report

15/12/1998

Name and mailing address of the ISA

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Castagné, 0

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 98/02234

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>EP 0 281 946 A (BOLT TECHNOLOGY CORP)  14 September 1988  see column 1  see figures 1,3-5</p>	1,2

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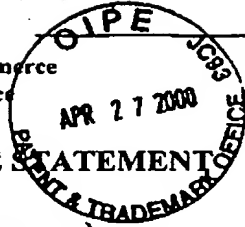
Information on patent family members

International Application No

PCT/GB 98/02234

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Form PTO-1449 U.S. Department of Commerce  
 (Rev. 2-82) Patent and Trademark Office



Atty. Docket No.  
 A32921 PCT USA

Serial No.  
 09/492,546

**INFORMATION DISCLOSURE STATEMENT  
 BY APPLICANT**  
 (Use several sheets if necessary)

Applicant  
 Richard H. Clarke et al.

**U.S. PATENT DOCUMENTS**

n.	Document No.	Date	Name	Class	Subclass	Filing Date if Appropriate

**FOREIGN PATENT DOCUMENT**

	Document No.	Date	Country	Class	SubClass	Translation Yes No
<input checked="" type="checkbox"/>	0 2 8 1 9 4 6	Sept. 1988	Europe	-	-	
<input checked="" type="checkbox"/>	1 7 7 2 7 7 5	Oct. 1992	Russia	-	-	
<input checked="" type="checkbox"/>	9 3 0 7 5 1 4	Apr. 1993	PCT	-	-	
<input checked="" type="checkbox"/>	9 7 1 4 9 8 0	Apr. 1997	PCT			

**OTHER DOCUMENTS (including Author, Title Date, Pertinent Pages, Etc.)**

<input checked="" type="checkbox"/>		International Search Report, PCT/GB 98 02234, December 15, 1998, 3 pp.

Examiner

*Anthony G. Joly*

Date Considered

8/27/00

Examiner: Initial citation considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.